51. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

PROCEEDINGS 11-15 September 2006

FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION SCIENCE

INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING - DEVICES AND SYSTEMS, MATERIALS AND TECHNOLOGIES FOR THE FUTURE

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion: Referat Marketing und Studentische Angelegenheiten
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
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Redaktionsschluss: 07. Juli 2006

Technische Realisierung (CD-Rom-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Marco Albrecht
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
ilmedia
Postfach 10 05 65
98684 Ilmenau

Verlag:
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilrnenau

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ISBN (Druckausgabe): 3-938843-15-2
ISBN (CD-Rom-Ausgabe): 3-938843-16-0

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

51st Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
September 11 – 15, 2006

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High Power RF and MF Systems for Sputter Applications in Flat Panel Display Production

Electro-Processing Technologies

ABSTRACT

The substrate size in flat panel display production is still increasing. Glass sizes of more than two by two meters are becoming a standard soon. The scaling in substrate size has a direct consequence to the related process power used for deposition and etching processes. For thin film transistor (TFT) displays an ongoing shrinking of the structural elements leads to the requirement of better film uniformity and a minimum amount of defects. The defect size is directly proportional to the remaining arc energy delivered by the power supply. For this reason a main demand for the next generation power supply is an arc energy as low as possible.

Beside this there is a need for decreasing production costs by a better productivity. This is mainly realized by a higher throughput of the coating equipment resulting in shorter cycle times. These short process times in addition with the trend to thinner layer thickness require a more and more precise control of the sputter power.

An inside view on the system requirements for next generation RF and MF generators used for flat panel display applications will be shown. These systems need a high precision process control and a supreme arc management with adaptable parameters to provide minimal disturbances in the plasma process and to obtain optimized results in terms of film quality, homogeneity and optical properties of the deposited film or during an etching process. RF systems with an output power of up to 50 kW and MF systems with up to 150 kW are presented with practical results from industrial coating applications.

INTRODUCTION

The demand for large color displays with high resolution is immense. For monitors and now for TV screens mainly the technology of LCD is used. On the other side the cost for these displays had to be reduced drastically to get the market access. The solution came from the use of substrates which have been increased in size from generation to generation. Starting with substrates of 300 x 400 mm in the middle of the 90s the actual sizes of glass substrates today are 1100 x 1300 mm (5^{th} generation, G5), 1500 x 1800 mm (G6) and 1870 x 2200 mm (G7). Right now the equipment for the next generation is on the way which will have a substrate size of 1800 x 2200 mm (G8).

Flat Panel Displays can be devided into passive and active matrix displays. In a passive matrix display the visible information represented by a row of pixels fades during the period of time needed to adress all the other rows in the display. A non-flickering image requires a balance of the display fade rate and the persistence of vision in the human eye. In an active matrix display each pixel is connected to its corresponding row and column electrodes by additional transistors keeping the pixels on or off, even when the row in which the pixel resides is not being addressed. Flickering is not a problem since the row of pixels remains static [1].

The function of a power supply are the power conversion from mains into different voltage and frequency levels, the isolation between mains and load and the dynamic control of the process power. Especially the dynamic range of the plasma impedance has to be considered in the design to cover the three states of the plasma and the transition between them: insulating gas, ignition, plasma, arc and arc quenching. A tiny distortion in a layer will immediately lead to a pixel defect in the end product.

For flat panel displays (FPD) the user focuses on the achievable sputter rates, the film quality and the cost of the resulting layer system. For these coating applications MF and RF generators in the power range of 30 kW up to 300 kW are commonly used to create stacks of various materials in in-line sputtering systems [2, 3, 4, 5]. With the introduction of materials like oxides and nitrides of aluminum or silicon the arcing has to be controlled especially at high power densities and increased sputter rates. Besides the system functions like process and gas control the generator with its arc management has a major role here.

Sputter deposited layers for flat panel display production are ITO and metallic layers as Al for gate and contact layers [6]. Sputtering is done using MF power standardly

The fabrication of LCD not only needs deposition processes. Hence partial removal of films is needed to create patterns of color filters and structural elements of active matrix LCD, sputtering processes like reactive ion etching are in place. RF is the preferred form of energy for these processes. As the glass substrates for LCD lines are increasing to more than 4 square meters the necessary RF power reaches 30-50 kW.

MF MAGNETRON DEPOSITION

Magnetron sputtering is used for the deposition of several layers of the display layer stack. An important application is the coating with transparent conductive oxides as ITO. This is done using DC or MF power supplies. Also metallic contact or gate layers as for example Al are standardly magnetron sputtered using DC processes. For all these layers a good thickness homogeneity of the deposited layers at high deposition rates is very important.

To meet the highly sophisticated requirements of Flat Panel Display Production on the MF process a new MF generator family was developed. In principle it consists of two parts, the DC supply unit and the MF unit. The DC unit consists of up to 4 modules with 30kW power each. The MF unit converts the direct voltage of the DC unit in a high frequency alternating voltage. The frequency depends on the components of the oscillator circuit, i.e. the value of capacitance and inductance. By varying the capacitor configuration, the frequency can be adapted to the process requirements. As the most important point a strongly improved arc management was introduced. The following criteria are evaluated for Arc detection and sets of these parameters can be used as presets in recipes.

- Absolute and dynamic limit values for voltage drop and current rise in the plasma
- Asymmetry of the current values of the two sputter cathodes. Here the generator compares the currents of the two cathodes separately from each other.
- Frequency changes
- Changes of the half-wave shape (short voltage drops)

As a reaction to the arc detection the power can be keyed off either immediately or after a certain delay. The power interruption is done via an additional fast arc switch. This technology enables arc detection and shut off times of 5µs and residual arc energies of 5mJ per kilowatt as shown in **fig. 1**.

The improved Arc management makes a significant contribution to the economy of the systems. Firstly, the fast and flexible arc handling leads to an improvement in the film

quality by minimizing flaws and defects. Secondly, very high sputter rates can be achieved because of the high process stability, which leads to an increase in productivity.

The minimization of the residual energy to only around 5 mJ per kilowatt yields additional advantages. Even when the cathode material is almost used up and consequently the arc probability increases, the low residual energy values contribute to an extended service life of the cathode and to better utilization of the target material.

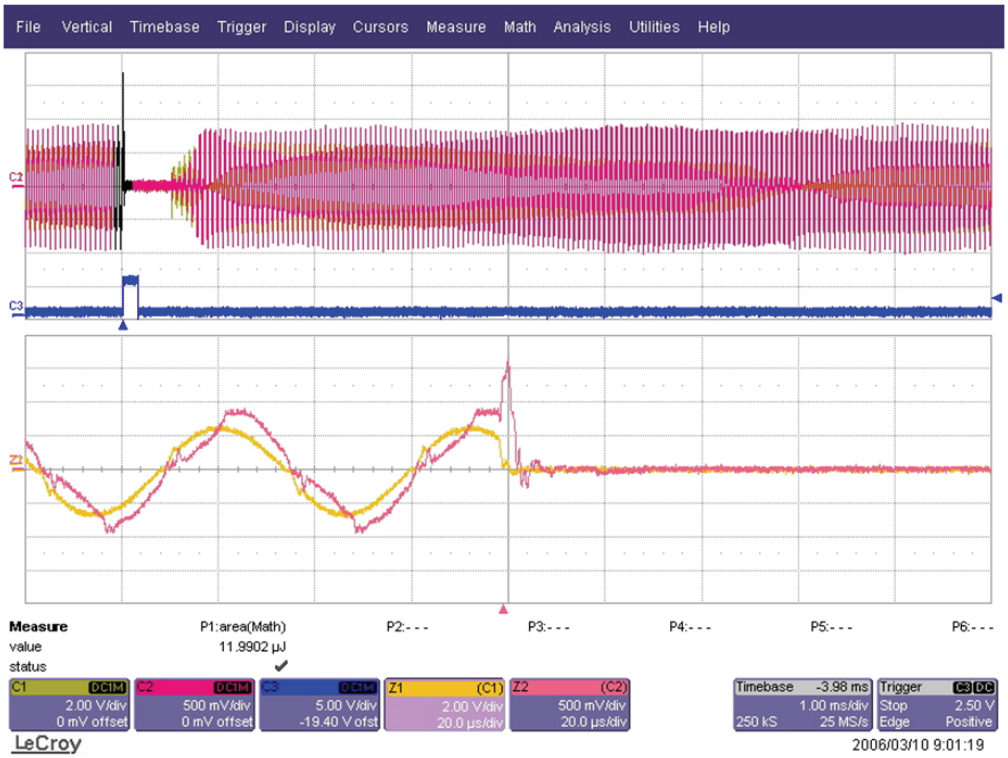

Figure 1: *Example of a fast arc handling of a MF Generator in reactive sputter mode at a planar magnetron (50 kW, 50 kHz, shut off time <5 µs)*

Essentially, the outstanding feature of effective arc management is an undisturbed plasma production operation. The fast arc suppression minimizes the interruption in the sputtering process to negligibly small values. However, because arcs also serve to remove unwanted materials on the cathode, power supplies must be able to control and regulate the arc energy precisely

RF POWERED ETCHING

Etching applications using RF power are reactive ion etching of Si_3N_4 and SiO_2 as well as plasma etching of polyimide layers. The RF energy scales up with the substrate

sizes: the required RF power reaches 20 kW for G5 production systems and 30-50 kW for G7 and G8 systems. The standard operating frequency is 13.56 MHz .

To have a cost effective design for a high power RF generator in this power range an oscillator - amplifier concept has been chosen with a solid state driver in combination with a tube type endstage amplifier.

Starting from 1 µW the signal is modulated for power control and pulsing functionality and then gets to the chain of amplifiers where the power of the modulated signal is increased in the pre-amplifier to a level of 100 mW and in the driver stage to a level of 4 kW. Finally, the robust tube type end stage creates the output power level of 50 kW

The output power which is delivered into the 50 Ohm coaxial cable is controlled and the incident and reflected part is measured by the directional coupler.

This system has proved it's robustness in many industrial coating lines. It has a compact size and can be easily integrated in a system. An detailed description can be found elsewhere [7].

Advanced etch systems for dielectric etch use a dual frequency capacitive discharge. **Fig. 2** shows two different configurations actually used.

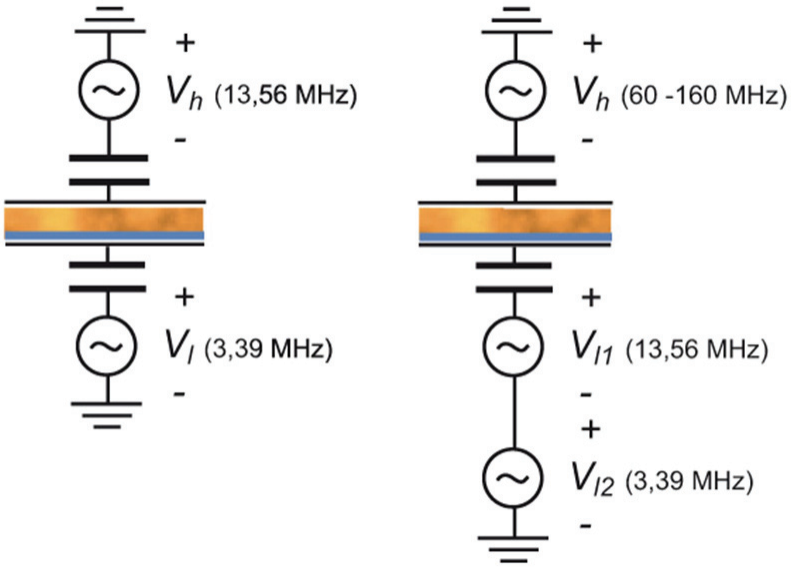

Figure 2: *Two different dual frequency capacitive discharge setup.*

The advantage of the dual frequency approach is the possibility of independent control of the ion flux and the ion energy [8,9] The high frequency voltage controls the ion flux while the ion energy is controlled by the low frequency voltage. The configuration with two frequencies at the substrate enables additionally the control of the ion energy

distribution. **Fig. 3** shows the schematical set up for the case of two frequencies connected to one electrode which is standardly the substrate.

A masteroscillator (MOP) controlls both, the 13.56MHz and 3.39MHz generators. Each of the generators is connected to a matching network often called matchbox.

The impedance of the cathode varies with the process in the range of 1-5 Ohms with a strong capacitive part. In contrast, the output impedance of the generator has 50 Ohms. In order to deliver the maximum output power of the generator to the chamber the impedance transformation network is needed.

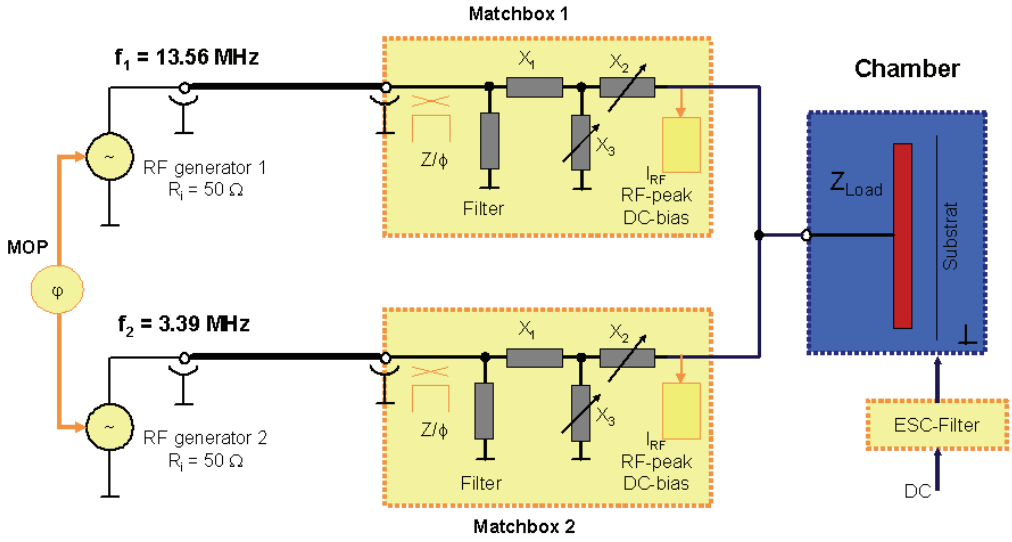

Figure 3: *Schematic for two frequencies at one electrode configuration.*

The impedance of the cathode is matched to the 50 Ohms by a network of three elements . To compensate the varying impedance of the process two of the three elements are variable by motor controlled vacuum capacitors. The resulting impedance of the matchbox and process parameters like the RF peak voltage and the DC bias voltage are measured and delivered to the controller inside the matchbox. These signals are also transferred to the generator which acts as a system controller.

Behind the matchbox the output power is combined and the mixed power is connected to the electrode holding the substrate.

A oscilloscope screenshot of the mixed power output is shown in **fig. 4**. In this case 18kW 3.39MHz power and 40kW 13.56MHz power have been mixed.

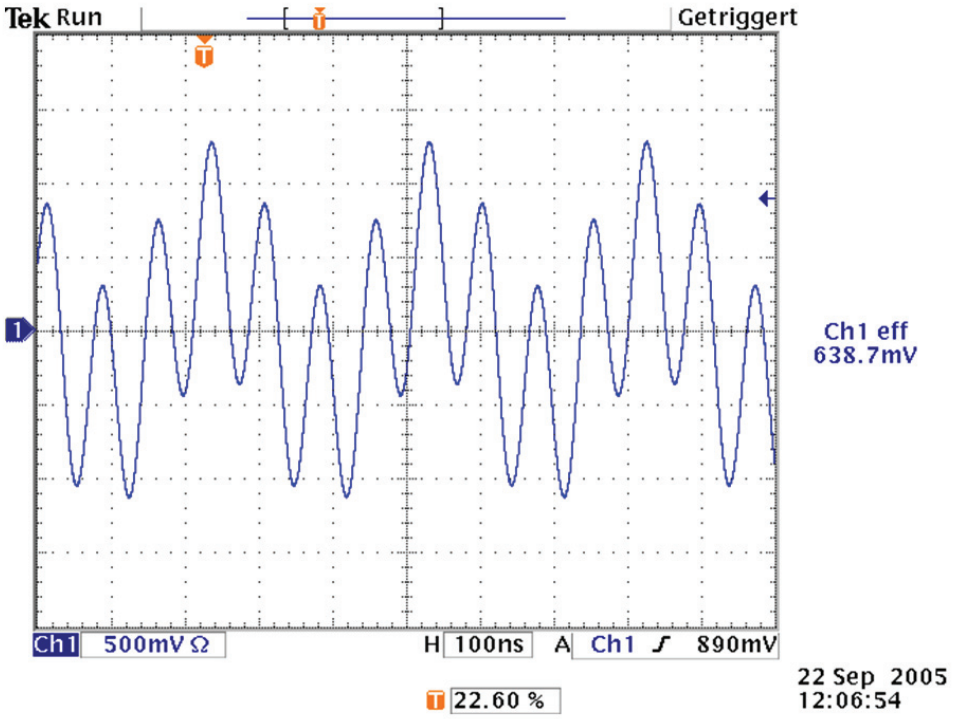

Figure 4: *Scope screenshot of mixed 3.39MHz and 13.56MHz power.*

SUMMARY

For the various sputter deposition and etch applications used for Flat Panel Display production high power MF and RF generators are available which meet the specific process related technical and economical requirements. As the substrate sizes in Flat Panel Display production reached several square meters not only MF generators are used in the high power range but also RF generators with an output power of 50 kW are needed and have been installed at industrial coating sites.

A new MF generator family with output power from 25kW to 100kW with an highly advanced arc management enabling shut off times of less then 5µs and residual energies of 5mJ/kW has been developed. For advanced dielectric etching processes a system to enable the generation of a dual frequency capacitive discharge was developed to independently control the ion flux and the ion energy of the discharge.

All these systems have a high precision process control and a supreme arc management with adaptable parameters to provide minimal disturbances in the plasma process. This enables the deposition of layers with optimized homogeneity, stoichiometry and optical properties. Also a precise control of the etching process is guaranted.

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